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ABSTRACT

The Kavesh's model of ribbon formation during the melt-spinning process has been discussed. It has been shown that a good agreement between the theoretical and the experimental results for both the variation of the ribbon dimensions and the behaviour of the melt puddle can be obtained only after the correction of the original equations.

АННОТАЦИЯ

Нами изучалось предложенное Кавешем описание лентообразующего процесса в течение "melt-spinning". Показано, что теоретические и экспериментальные результаты изучения изменения размера ленты и поведения расплавленной капли совпадают только после коррекции оригинальных уравнений.

KIVONAT

Megvizsgáltuk a "melt-spinning" eljárás során fellépő szalagképződési folyamat Kavesh által javasolt leirását. Megmutattuk, hogy a szalagméretek változására és az olvadéktócsa viselkedésére vonatkozó elméleti és kisérleti eredmények csak az eredeti egyenletek korrekciója után hozhatók összhangba.

Several phenomenological relations are available for the dependence of the ribbon geometry on the technological parameters during the melt-spinning process [1-4]. The most often quoted relationships are obtained from the thermal transport controlled ribbon formation model of Kavesh [5]:

$$\bar{\delta}_R = \frac{1}{c''} \frac{Q^{0.25}}{V_o^{0.75}} \quad \text{and} \quad w_R = c'' \frac{Q^{0.75}}{V_o^{0.25}} \tag{1a,b}$$

where $\bar{\delta}_R$ and w_R are the average thickness and the width of the ribbon, respectively, Q is the volumetric rate of melt flow, V_o is the surface velocity of the cooling substrate and c" is a proportionality constant independent of the casting parameters, Q and V_o. These expressions are in a fair agreement with the experimental results [3,5-7]. However, this agreement is surprising because the derivation of Eqs. (1a,b) is based on a melt puddle behaviour which is in clear contradiction with the experimental findings [6]. We will show that the mathematically correct treatment of the Kavesh's model changes significantly the relations between the ribbon dimensions and the casting parameters.

Impinging to the surface of the moving substrate the melt jet forms a puddle (see Fig. 1), under which the solid layer thickens according to the relation:

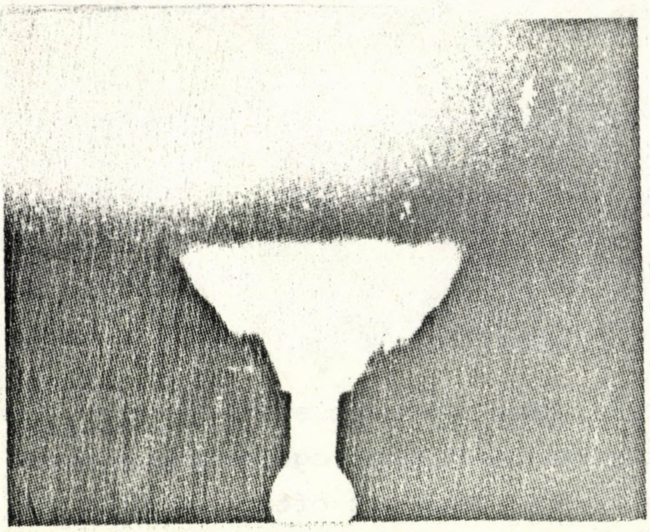
$$\delta_s(\xi) = c_o\left(\frac{\xi}{V_o}\right)^m \tag{2}$$

where δ_s is the thickness of the solid layer, c_o and m are the parameters characteristic to the mechanism of solidification, while ξ is the length measured from the front edge of the puddle in the direction of the movement of the substrate surface.

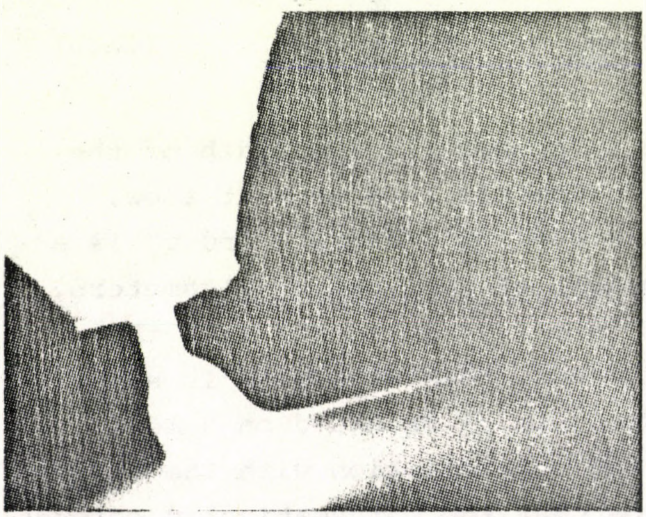
The cross-section geometry of the ribbon is determined by the form of the puddle base. It is reasonable to assume that the latter can be described by a function containing two parameters:

$$\frac{x}{\ell/2} = f\left(\frac{y}{w/2}\right) \qquad (3)$$

where ℓ is the length and w is the width of the puddle, which is supposed to be equal to that of the ribbon $w = w_R$. The x-y plane corresponds to the surface of the substrate, while the origo is fixed to the midpoint of the puddle base, and the x-axis is in the direction of the movement of the substrate.



a,



b,

Fig. 1. The melt puddle formed by the melt jet on the surface of the substrate
a/ front view
b/ lateral view

Combining Eq. (2) with Eq. (3) the thickness measured at point y along the width of the ribbon can be given as:

$$\delta_R(y) = \delta_s(\xi = 2x(y)) = c_o\left\{\frac{\ell f\left(\frac{y}{w/2}\right)}{V_o}\right\}^m \qquad (4)$$

Taking into account the mass flow balance, the volumetric rate of flow in the jet and in the ribbon is equal:

$$Q = \bar{\delta}_R w_R V_o \tag{5}$$

where $\bar{\delta}_R$ is the average ribbon thickness defined by:

$$\bar{\delta}_R = \frac{2}{w} \int_o^{w/2} \delta_R(y)\,dy \tag{6}$$

while $\delta_R(y)$ has to be taken from Eq. (4).

The equation of Kavesh for the average ribbon thickness (Eq. (4) of [5]) does not contain the 2/w normalization factor, which makes $\bar{\delta}_R$ dimensionally incorrect. This shortage in 2/w can be followed all along his calculations (see Eqs. (5-17) of [5]). We will show that it results in a significant change of the casting parameter dependence of the ribbon dimensions.

To determine the connection between the casting parameters (Q and V_o) and the ribbon dimensions ($\bar{\delta}_R$ and w_R) we need a further relation, namely that of the dependence of the form of the puddle upon the values of Q and V_o:

$$\ell = \ell(w;Q,V_o) \tag{7}$$

In the frame of the above phenomenological formulation the properties of the material are represented by c_o,m and Eq. (7). If these informations are given we can predict the ribbon geometry for a given technological parameter set (Q and V_o).

In his work Kavesh applied c_o and m values derived from a theoretical model refered to as heat transport controlled ribbon formation. He supposed a puddle behaviour described by the following form of Eq. (7):

$$\frac{w}{2}\,\frac{\ell}{2} \cong \text{const.} \tag{8}$$

which means, that the puddle base area is independent of Q and V_o. It must be mentioned that this supposition is in clear contradiction with the experimental observations of both Hillmann and Hilzinger and Vincent et al. [6,7]. They found that under constant Q the puddle length decreased for increased V_o. Taking into account that under such conditions an increase in V_o cannot enlarge the width of the puddle, Eq. (8) prescribes a variation of ℓ opposite to the observed case. The original expressions obtained by Kavesh for the ribbon dimensions are the following:

$$\bar{\delta}_R = \frac{1}{c''} \frac{Q^{\frac{1-m}{2-m}}}{V_o^{\frac{1}{2-m}}} \quad \text{and} \quad w_R = c'' \frac{Q^{\frac{1}{2-m}}}{V_o^{\frac{1-m}{2-m}}} \qquad (9a,b)$$

which give Eq. (1a,b) with the parameters of the heat transport controlled ribbon formation (m=0.67, [5]).

In the following short calculation we intend to show how the proper normalization of $\bar{\delta}_R$ changes the results of Kavesh. First we recall a special form of the equation for the volumetric flow balance proposed by him:

$$c''\, w^{2-m}\, V_o^{1-m} = Q \qquad \text{Eq. (13) of [5]}$$

The proper normalization contributes and extra 2/w factor. It can be seen by substituting Eqs. (4,6) and Eq. (8) to Eq. (5) that:

$$2c''(w\, V_o)^{1-m} = Q \qquad (10)$$

As this relation should hold for every V_o value for a given Q this expression requires $w \sim V_o^{-1}$. Combining this result with Eq. (5) we can realize that $\bar{\delta}_R$ turns out to be entirely independent of V_o.* This way we have shown that starting from the unphysical assumption of Eq. (8) the correct equations lead to relations contradicting the experiments. It means that the missing 2/w factor is the only reason why the unphysical puddle behaviour leads to acceptable casting parameter dependence of the ribbon dimensions within the frame of the model of Kavesh.

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*The independence of $\bar{\delta}_R$ of V_o is a straightforward consequence of Eq. (8) irrespectively of the value of m, as it can be seen from the form of Eq. (10).

Let us test the correct equations by using a more realistic relation for the description of the puddle behaviour e.g. by the simplest approximation suggested by Vincent et al. [7], which describes the trends well:

$$\frac{\ell}{w} = K_1 \tag{11}$$

where K_1 is a dimensionless constant, independent of Q, V_o, w and ℓ. A more detailed expression for the average ribbon thickness can be presented by substituting Eq. (4) into Eq. (6):

$$\bar{\delta}_R = K_o\ c_o \left(\frac{\ell}{V_o}\right)^m \tag{12}$$

where $K_o = \int_o^1 f^m(\zeta)d\zeta$ is a dimensionless constant, independent of Q, V_o, w and ℓ. Evaluation of the volumetric flow balance by inserting Eq. (11) and Eq. (12) into Eq. (5) yields the following formulae for the ribbon dimensions:

$$\bar{\delta}_R = K \frac{Q^{\frac{m}{m+1}}}{V_o^{\frac{2m}{m+1}}} \quad \text{and} \quad w_R = \frac{1}{K} \frac{Q^{\frac{1}{m+1}}}{V_o^{\frac{1-m}{m+1}}} \tag{13a,b}$$

where $K = K_o c_o K_1$. These expressions coincide with those derived by Vincent et al. [7]. According to this fact the theoretically derived limiting values of m lead to the following results:

a/ Ideal cooling, m=0.5 [8]:

$$\bar{\delta}_R \sim \frac{Q^{0.33}}{V_o^{0.67}} \quad \text{and} \quad w_R \sim \frac{Q^{0.67}}{V_o^{0.33}} \tag{14a,b}$$

b/ Newtonian cooling, m=1 [9]:

$$\bar{\delta}_R \sim \frac{Q^{0.5}}{V_o} \quad \text{and} \quad w_R \sim Q^{0.5} \tag{15a,b}$$

demonstrating that choosing an appropriate value of m (e.g. m = 0.7) the relations following from Eqs. (13a,b) are able to describe the approximate casting parameter dependence of the ribbon geometry.

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REFERENCES

[1] H.H. Liebermann, C.D. Graham, IEEE Trans. Mag. MAG-12, 921 /1976/

[2] H.H. Liebermann, Mater. Sci. Eng. 43, 203 /1980/

[3] S.J.B. Charter, D.R. Mooney, R. Cheese, B. Cantor, J. Mater. Sci. 15, 2658 /1980/

[4] S. Takayama, T.Oi, J. Appl. Phys. 50, 4962 /1979/

[5] S. Kavesh, "Metallic Glasses", ed. J.J. Gilman, H.J. Leamy, /1976/ Metals Park, Ohio, The American Society for Metals, p. 36

[6] H.H. Hillmann, H.R. Hilzinger, "Rapidly Quenched Metals III", ed. B. Cantor, /The Metals Society, London, 1978/ Vol. 1, p. 22

[7] J.H. Vincent, H.A. Davies, J.G. Herbertson, Proc. Symp. on Continuous Casting of Small Cross-Sections, Pittsburgh 1980, in the press and J.H. Vincent, J.G. Herbertson, H.A. Davies, Proc. 4th Intl. Conf. Rapidly Quenched Metals, Sendai, Japan 1981, in the press

[8] H.S. Carslaw, J.C. Jaeger, Conduction of Heat in Solids, Oxford University Press, Oxford U.K. /1959/

[9] P.H. Shingu, R. Ozaki, Met. Trans. A, 6A, 33 /1975/

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